Improving the resistance to sulphuric acid attack of precast concrete pipes with polymers. Technical and economical considerations.

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ABSTRACT: Several studies have already been conducted showing that polymer addition and polymer impregnation can improve the durability of concrete structures. Nevertheless, although technically speaking the two options are both to merit their economic impacts are yet to be analysed. This manuscript report results of a wider investigation which aims to understand what is the best option for the concrete pipe industry as far as chemical acid resistant is concerned, polymer addition or polymer impregnation. Results show that the use of polymer addition it is not economically attractive. The use of polymer impregnation enhances the chemical resistance of concrete considerably and this solution is economically viable, especially for smaller diameters.

1 INTRODUCTION

The first patent on hydraulic binders modified with polymers was issued in 1924 (Ohama, 1998). However, only in the 50's appeared the first uses of concrete modified with polymers, particularly in the rehabilitation of concrete structures.

At present three kinds of polymer based concrete can be separated due to their different nature. One group is related to polymer modified concrete - PMC or "polymer cement concrete" – PCC and is composed of aggregates and a binder matrix where phases generated by the hydration of Portland cement coexists with polymeric phases. Another group is related to polymer impregnated concrete - PIC, in which concrete are impregnated with a monomer of low viscosity, usually of methyl methacrylate in order to fill its porous structure. A third group is related to polymer concrete – PC, this group is composed of aggregates and a polymer matrix without Portland cement (Fowler, 1998).

For PMC, additives are added to concrete during the mixing stage, usually in the form of a colloidal suspension of latex, powder, or as water-soluble polymers or liquids, and the literature usually refers to more used the polymer of styrene-butadiene (SBR) of polyacrylic-ester (PAE), polyethylene vinyl acetate (EVA). These materials are know to possess superior durability over ordinary Portland cement concrete, assessed by resistance to acid attack (Monteny et al., 2001), resistance to action of ice-melting (Chmielewska, 2007), resistance to diffusion of chlorides (Yang et al., 2008). The explanations for this difference in behaviour are due to one hand, to a lower porosity of the formation of a polymer film inside the pores (Rossignolo, 2005) and to a low permeability to water access (Neelamegan, 2007).

Several authors show that polymer addition and polymer impregnation of concrete materials may lead to an increase durability depending of the type of polymers that are used (Moreira et al., 2006; Ogawa et al., 2007; Shirai et al., 2007). Nevertheless, there are not studies that could help to understand what is the best option economically speaking, i.e, polymer addition or polymer impregnation are both to merit as far as industrial production is concerned?

In this manuscript technical and economic data is presented in order to help a better judgment about the previous question.

2 EXPERIMENTAL PROGRAM

The experimental work is based in 9 mixtures (5 mortar and 4 concrete mixtures). The first and second sets of mortar mixtures are meant to assess the performance respectively of polymer modified mortars and polymer impregnated mortars.

Five mortars mixtures were made with two different W/C ratios and two different melamine percentages (Table 1).

Table 1: Mortar mix proportions.

	Cement g	Sand (2-3mm) g	Melanines ml.		Water ml.	W/C
			Solid	Liquid		
Control	450	1350	0		225	0,5
M_0.8-0,5	450	1350	3.8		221.2	
			0.8	3		
M_0.8-0,4	450	1350	3.8		177	0,4
			0.8	3		
M_2.0-0,5	450	1350	9		216	0,5
			1.9	7.1		
M_2.0-0,4	450	1350	9		171	0,4
			1.9	7.1		

Mixtures with a melamine percentage of 0,8 and a W/C ratio of 0,5 where named M_0,8_0,5. Mortar specimens with 40x40x40 mm^3 were moulded and cured at 40 ºC during 9 days that correspond to cure 28 days at 18±1 ºC. A set of mixtures specimens were impregnated with melamine and they were cured in air during 48 hours to allow melamine to polymerize. Concrete mix proportions are shown in Table 2.

Table 2: Concrete mix proportions per cubic meter of concrete.

Components	Concrete mix			
	Control	PM_M_2	PM_SK_10	PM_PCI_10
Cement 32,5 (Kg)	320.0	320.0	320.0	320.0
Fine sand (0-1mm) (Kg)	600.0	600.0	600.0	600.0
Sand (2-3mm) (Kg)	600.0	600.0	600.0	600.0
Coarse aggregate 5/15 (Kg)	800.0	800.0	800.0	800.0
Coarse aggregates 12/15 (Kg)	400.0	400.0	400.0	400.0
Admixture (L)	--	6.40	85.70	77.70
Water (L)	227.0	212.0	162.0	162.0
A/C	0.709	0.663	0.506	0.506
Solid Polymer/C	--	0.004	0.096	0.092

Three modified polymer mixtures were made. PM_M_2 stands for 2% melamine addition, PM_SK_10 for 10% styrene-butadiene latex addition and PM_PCI_10 for 10% styrene-butadiene emulsion addition.

The chemical resistance was performed with a pH=0,7. After curing time, i.e, 28 days, the concrete specimens were exposed to sulphuric acid while the reference specimens were conditioned in water. Chemical resistance was assessed by an evaluation on compressive strength and weight reduction. The exception was for concrete specimens that were tested only by weight reduction. Concrete samples were taken from concrete pipes. The compressive strength was determinate following the ISO 4012.

3 RESULTS AND DISCUSSION

Weight reduction of polymer modified mortars is shown in Fig.1.

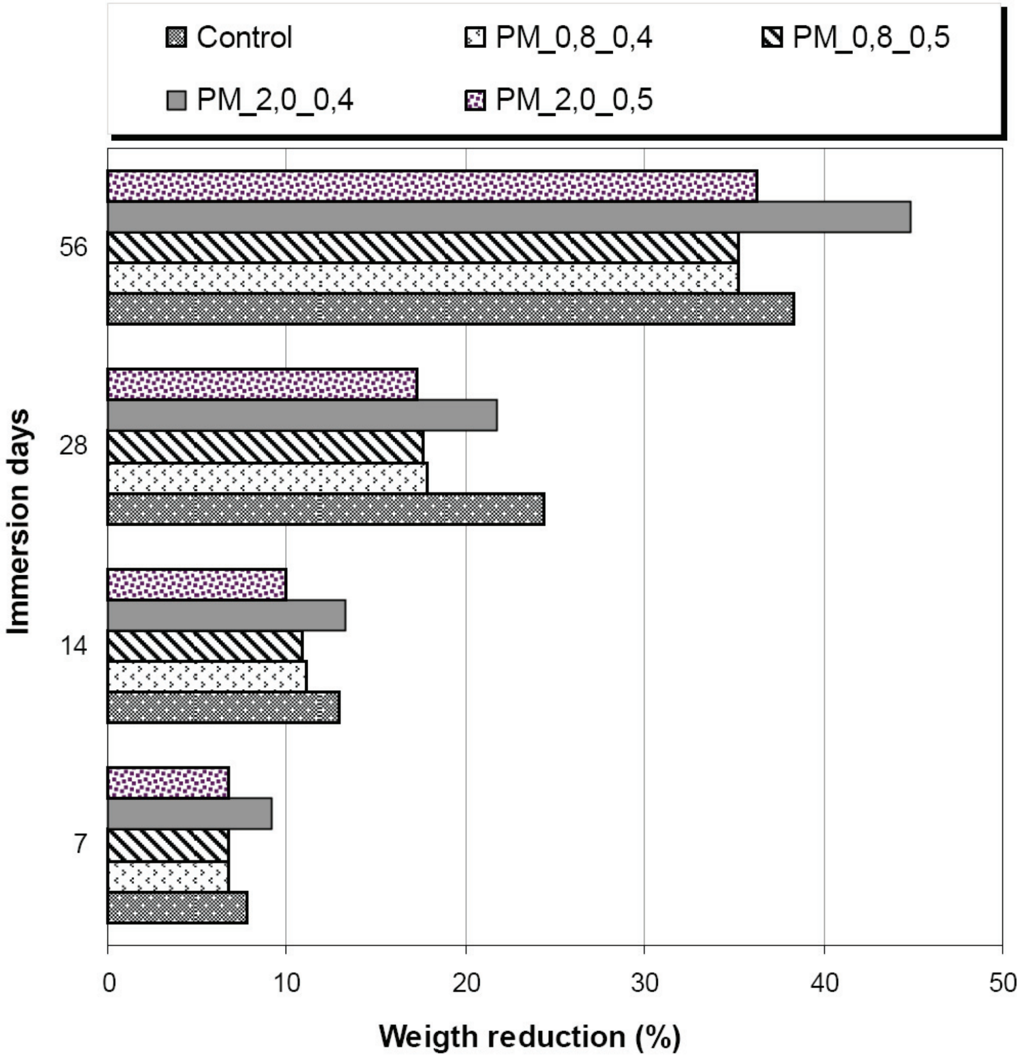

Figure 1: Weight reduction of polymer modified mortars.

With exception of 2% melamine addition and W/C=0,4 all mixtures perform better than the control mixture. It seems that for the 0,8% addition there is not much difference using 0,4 or 0,5 W/C ratio. But for the 2% melamine addition a decrease in W/C from 0,5 to 0,4 brings a worst performance for all curing ages. Using melamine addition is responsible for minor weight reductions when a comparison with the control mortar is made between 9 to 18%. Compressive strength of polymer modified mortars is shown in Fig. 2.

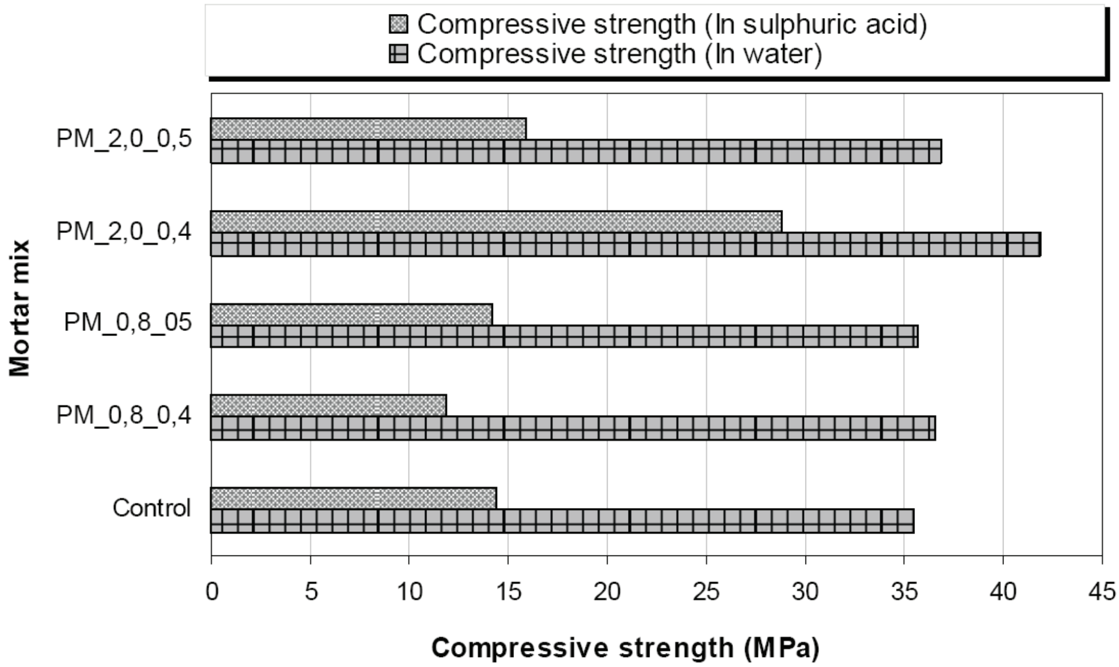

Figure 2: Compressive strength of polymer modified mortars.

Except for the case of the mixture with 2% of melamine and a W/C=0,4 it could be said that melamine addition is not an effective addition to increase sulphuric acid resistance. But the fact is that the mixture with the best performance is the mixture that had the higher weight loss. Since weight loss seems to be a more accurate measure of chemical resistance the results of compressive strength should be viewed with caution. The other three mixtures performed worst than the control mixture. It's not possible to say that compressive strength reduction is influenced by the water/cement ratio. When a polymer percentage of 0,8 is used reducing water ratio increases strength reduction but when the polymer percentage is 2% a decrease of W/C ratio is associated with a minor strength reduction. For the concrete specimens all mixtures with polymer addition perform worst than the control mixture (Fig.3).

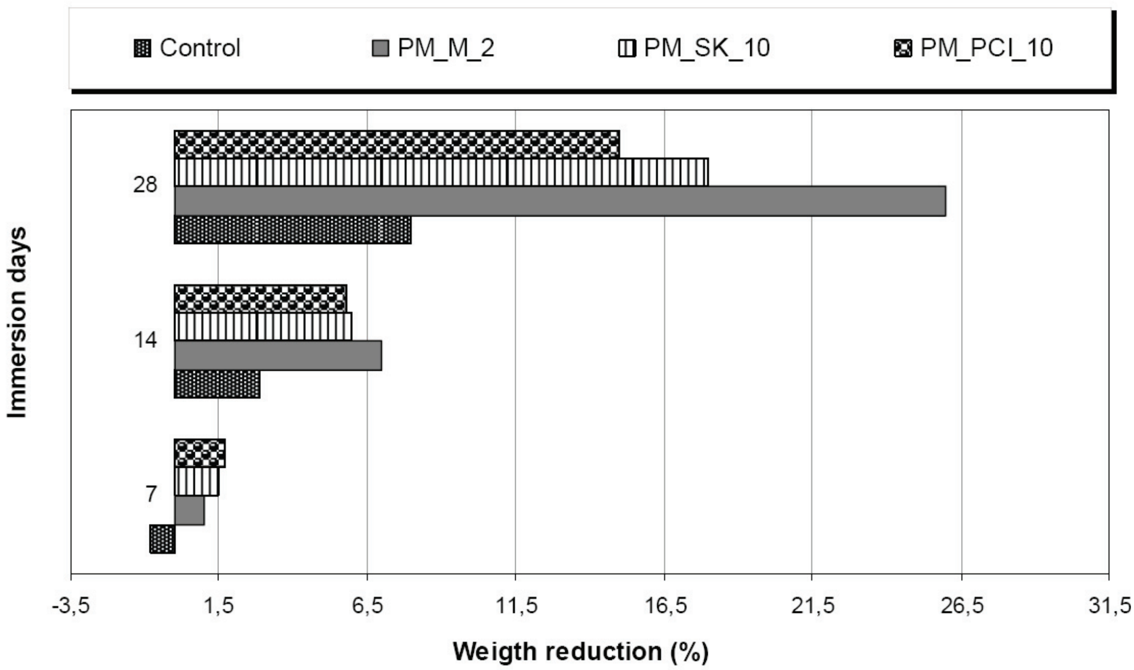

Figure 3: Weight reduction of polymer modified concrete.

The weight reduction is very dependent of the polymer type and from the time exposed to acid solution. Although melamine addition performed better for 7 days it had the worst performance for 14 and 28 days.

Results show that polymer impregnation for this particular condition is not an effective way to increase sulphuric acid resistance since all the mixtures perform worst than the control mixture (Fig. 4).

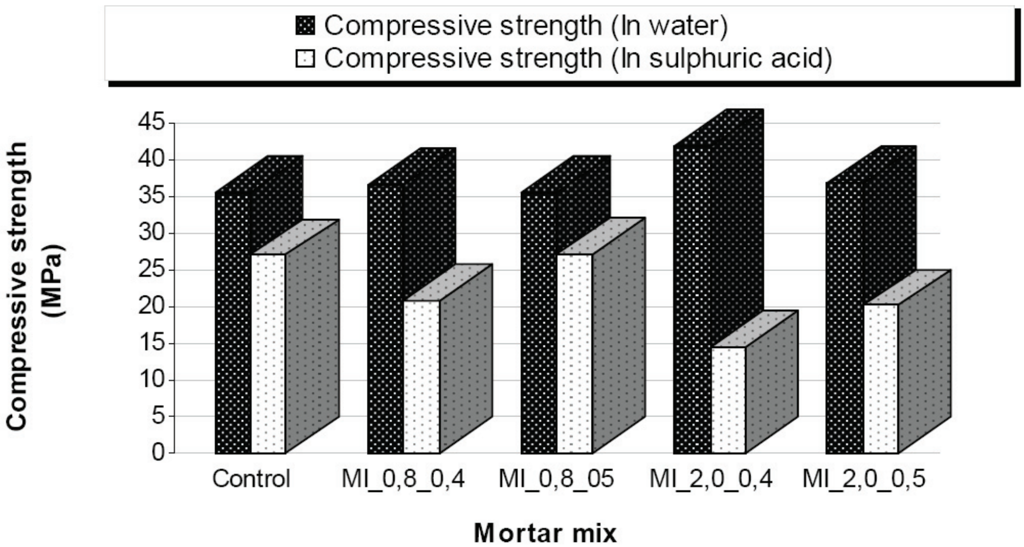

Figure 4: Compressive strength of polymer impregnated mortars.

Nevertheless, strength reduction is far lower for polymer impregnation than for polymer addition. The exception seems to be the mixture with a percentage of 2% melamine and a W/C=0,4. The best compressive strength result is obtained by the mixture with a 0,8 melamine percentage that has the same performance of the control mortar. Increasing melamine to 2% leads to a higher strength loss (45,5 – 65,6%). Compressive strength reduction seems to be influenced by the water/cement ratio. Reducing W/C from 0,5 to 0,4 is responsible for a major compressive strength reduction. For polymer impregnated mortars results show that all mixtures perform worst than the control mixture (Fig.5).

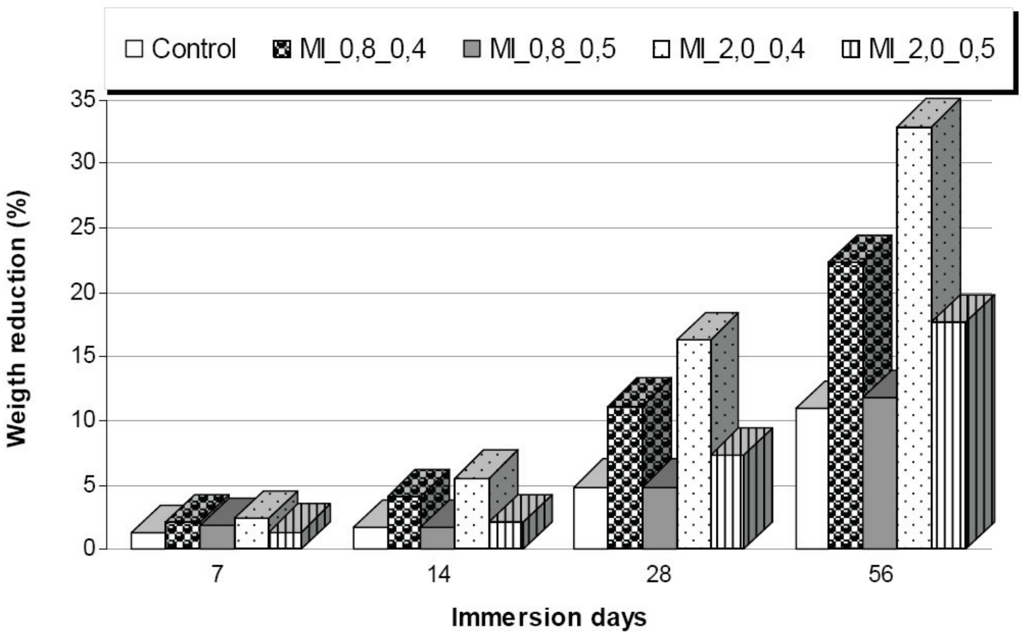

Figure 5: Weight reduction of polymer impregnated mortars.

Nevertheless, polymer impregnation performs better than polymer addition. For 7 days all specimens had a weight reduction below 5%. For concrete specimens (Fig.6), weight reduction results show that polymer impregnation performance is influenced by the polymer type. Being that the minimum weight loss takes place when the melamine impregnation was used. Polymer modified concrete it's not a viable solution since it implies a very high cost (Table 3).

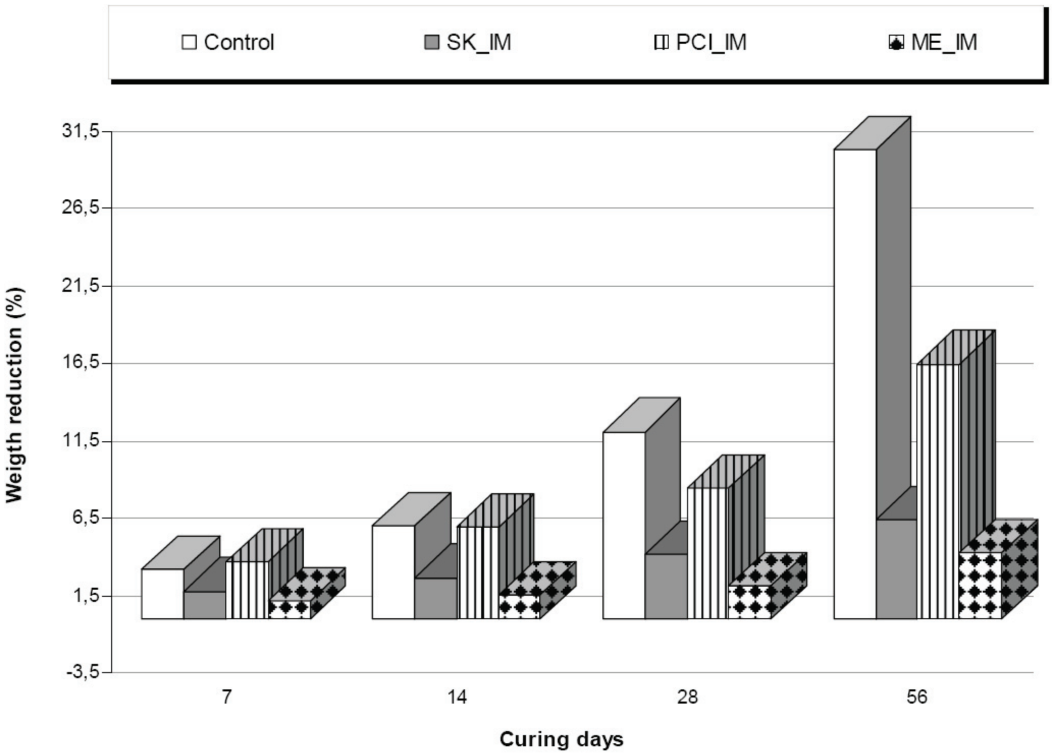

Figure 6: Weight reduction of polymer impregnated concrete.

Table 3: Polymer modified concrete pipe costs.

Pipe diameter (m)		0,15	0,2	0,3	0,4	0,5
Pipe Volume (m^3)		0,011775	0,01884	0,02826	0,05024	0,0785
Current coating cost/pipe (euro)		3,00	3,35	4,20	5,85	6,80
Current coating cost/m^3 (euro)		254,78	177,81	148,62	116,44	86,62
Liters of styrene-butadiene latex per m^3 (l)		28	20	17	13	10
Liters of styrene-butadiene emulsion per m^3 (l)		61	42	35	28	21
Liters of melamine per m^3 (l)		150	105	87	68	51
% of solids	Styrene-butadiene latex	3,2	2,2	1,9	1,5	1,1
	Styrene-butadiene emulsion	7,2	5,0	4,2	3,3	2,4
	Melamine	9,8	6,9	5,7	4,5	3,3

Polymer impregnated concrete has much lower costs especially for small pipe diameters (Table 4).

Table 4: Polymer impregnated concrete pipe costs.

Pipe diameter (m)	0,15	0,2	0,3	0,4	0,5
Cost/ml (euro)	4,95	5,25	8,40	10,40	15,00
Weight (kg)	44	54	105	165	245
Current coating cost (euro)	3,00	3,35	4,60	6,25	7,30
Styrene-butadiene latex absorption (l)	2,9	3,6	7,0	11,0	16,3
Styrene-butadiene latex impregnation cost (euro)	26,33	32,32	62,84	98,75	146,63
Cost increase with styrene-butadiene latex (%)	778	966	1941	3083	4644
Styrene-butadiene emulsion absorption (l)	3,17	3,89	7,57	11,90	17,66
Styrene-butadiene emulsion impregnation cost (euro)	13,32	16,35	31,80	49,97	74,19
Cost increase with styrene-butadiene emulsion (%)	344	388	591	699	916
Melamine absorption (l)	1,95	2,40	4,66	7,33	10,88
Melamine impregnation cost (eur)	33,2	40,8	79,3	124,5	184,9
Cost increase with melamine (%)	11	24	111	207	373

4 CONCLUSIONS

This study investigated sulphuric acid resistance of precast concrete pipes with polymers. Based on the experimental results the following conclusions can be drawn. The use of polymer modified concrete showed minor beneficial effect on the durability and acid resistance of concrete pipes. Nevertheless, this option is not economically attractive, because the increase of costs per meter of pipe is too high. The use of polymer impregnation enhances the chemical resistance of concrete and this solution is economically viable, especially for smaller diameters.

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